A MICRO TURBINE POWER SOURCE FOR DEEP SPACE APPLICATIONS

Interim Report

JPL Task 1027

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A. OBJECTIVES

The objective of this project is to fabricate a miniature-scale turbine using a novel fabrication method: three-dimensional LiGA using an inverse tomography approach. To put this effort into context, some information on this approach is appropriate.

As micro-fabrication technologies have matured, fabrication approaches have been driven by strategies of how micro-systems should be built. Some paths once thought to be promising, like monolithic electromechanical systems built from one standard process, have been largely abandoned in favor of others that offer solutions to problems that were not originally envisioned. As the strategy of "one process for everything" has faded, micro-systems built from two or more processes with later assembly has come to be thought of as the way these systems should be built. As this strategy has taken root, processes to build micro-parts for later assembly have become more central to whole area of micro-fabrication. Moreover, it has become clear that, while micro-systems are an idea whose time has come, meso-scale and even macro-scale systems can benefit from the use of micro-scale parts in some of their sub-systems.

LiGA (**Li**thographie **G**alvanoformung **A**bformung -- a German acronym meaning lithography, electroplating, and mold-making -- describes the processing steps involved in this technology) has become the prime approach for making precise micro- and meso-scale parts for many systems on all scales. Describing the process in brief: the long polymer chains in a high-molecular-density acrylic are broken up by exposure to soft x-rays generated by a synchrotron source. The acrylic is patterned by blocking some of the x-rays with a patterned gold mask. The acrylic is then placed in a developing bath to remove the exposed acrylic, leaving the unexposed material in the desired pattern. The acrylic is then used as a mold for electroplating (Fig #1).

Figure 1

Efforts to expand the range of parts that can be fabricated by LiGA are ongoing around the world, and JPL is a leader in this research. The limits being challenged are the thickness of the acrylic that can be patterned, and the hitherto inability to pattern parts in the "z" direction.

The technical approach of this project is to expand LiGA technologies into the area of 3-D parts using inverse tomography. Traditional LiGA parts are called 2-D because parts are only patterned in the x-y plane. The z dimension is always a straight vertical sidewall (Fig #1). So gears can be made, but not spheres.

However, tomography, the ability to reconstruct three-dimensional objects using two-dimensional projections, is a natural solution to the problem of fabricating three-dimensional LiGA parts. In theory, by using multiple masks and dynamic scanning techniques, exposed and developable areas within a substrate can assume arbitrarily complex shapes.

This project will use this capability to fabricate the compressor, the key element in the micro turbine power source.

B. PROGRESS AND RESULTS

The milestones for this project are:

- Design and build first-generation scanner module (no computer control).
- Design simple 3-D shape(s) to be fabricated.
- Fabricate 3-D part using first-generation scanning module.
- Design computer-controlled 3-D scanner with multiple degrees of freedom control.
- Software for performing translation from 3-D CAD model to projections to scanning motions.
- Build computer-controlled scanner.
- Design miniature turbine using data on process specifications.
- Design masks for compressor exposure.
- Fabricate compressor.

The initial steps in this project focused on creating a part using the basic idea, but without the computer-controlled scanner. The inverse tomography of the chosen shape, a cone (Fig #2), was straightforward, and only a single mask was necessary. To create this form within the substrate, a complex scanning scheme was used, using two scanners (Fig. #3), one mounted on the other to create the necessary complex motion.

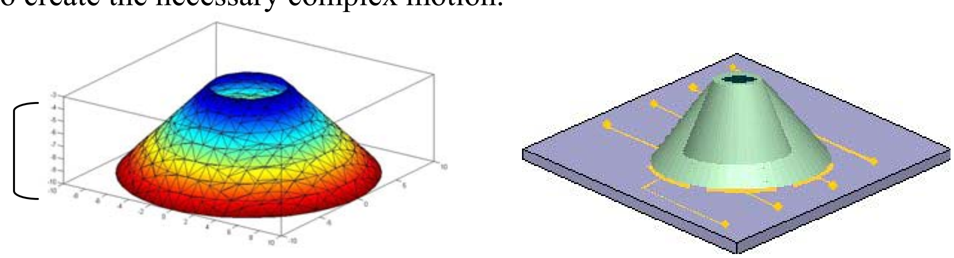
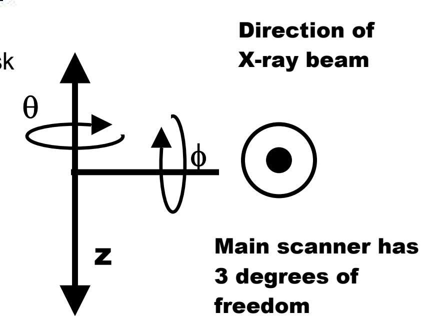


Figure 2: Initial design: simple cone fabricated using one mask and a two degree of freedom scan. The Z axis is no longer a straight sidewall.



The main scanner (Fig 4) has 3 programmable degrees of freedom: along the z axis, θ rotates around the z axis, and ϕ rotates around the axis perpendicular to the incoming x-ray beam. However, θ and ϕ rotations can only go 180 degrees, so full rotations cannot be achieved using this scanner alone. To accomplish this, and to implement the fabrication of the cone, another scanner was built to mount on the front end of the larger scanner and sit in the path of the beam (Fig.#4)

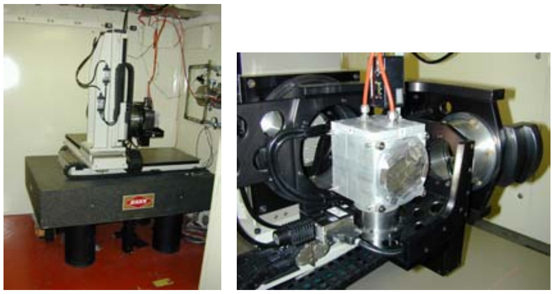


Figure 3: LiGA scanner with 3 degrees of freedom. Samples are mounted on the front block.

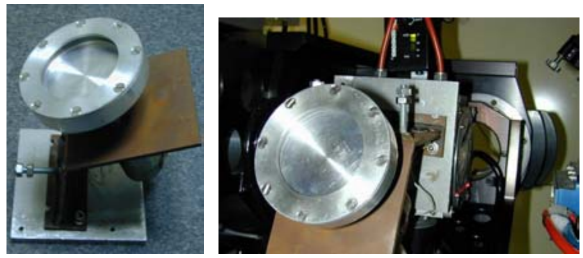
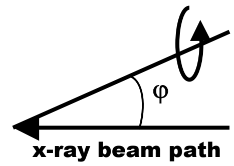


Figure 4: Rotary Scanner is mounted on the LiGA scanner.

This rotary scanner holds the sample at an angle to the path of the incoming beam and rotates. For this sample, two scanning motions were used: along the z axis, and rotation.

The results of the initial experiments were successful in exposing and developing a 3-D LiGA structure (Fig 5,6). Figure 7 shows the results of electroplating, which resulted in only a partially-plated cone. This step is the completion of the first three milestones.



Sample rotates at an angle from the incoming beam. This angle φ **defines the vertex angle of the cone.**

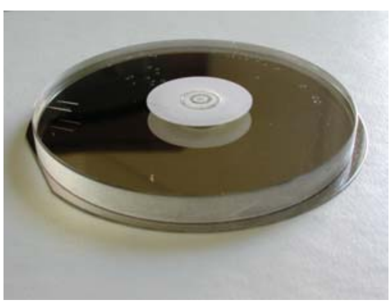


Figure 5: Exposed and developed substrate. 3-D structure is in the center**.**

Figure 6: Close-up of 3-D micro-mold ready to be electroplated.

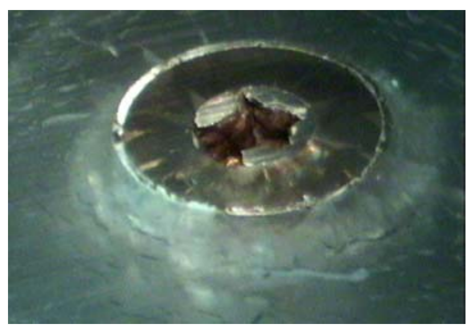


Figure 7: Electroplated cone

A more versatile scanner is needed for true inverse tomagraphic LiGA. The scanner module used in the initial experiments was for a simple proof-of –concept test. The next-generation scanner is also capable of rotation, is adjustable, and with computer control, is programmable. In addition to the rotation, it has 3 degrees of freedom along the x,y,z axes. This scanner is also a module and is mounted on the main LiGA scanner and used in conjunction with the programmable motions of that scanner.

The new scanner was designed in conjunction with Swales Aerospace with finished designs submitted July of 2002. Currently, Swales is awaiting the final contract to build the new scanner.

The software for the project falls into two categories: first, the software to run the scanners, and second, the algorithms to perform the inverse tomography. The scanners are run by LabView, and programming the drivers is currently being done by Cheryl Hauck -- an employee of the Advanced Light Source at Berkeley Labs, who acts as beamline coordinator for our beamline -- and myself. The driver software is in the 3rd generation, and successfully controls the scanner's 3 axes. Currently, we are working on an interface that allows the input from the inverse tomographic calculations.

The second piece of software is for calculating the inverse tomography, given the scanning parameters of our scanners and the shape desired. This code is still in the initial stages of defining the relevant algorithms.

The shape of the turbine is being modeled after an existing compressor. This model will be imported into a computational fluid dynamics program. Using the CFD program, the effectiveness of the compressor blades will be determined, and modifications will be made to the blades accordingly. By varying the shape and size of the blades of the compressor, an optimal blade shape and size can be chosen. Once the optimal shape of the blades is determined, the design will be scaled down to the appropriate size for a LiGA-fabricated micro-turbine. This shape will be represented as a vector array, and used as the input for the inverse tomographic calculation along with the parameters from the scanners.

With the completion of the new scanner and the mathematical representation of the compressor to be used in the design of the masks and scanning strategy, the systems will be in place to fabricate the first of the miniature compressors.

C. SIGNIFICANCE OF RESULTS

If true micro-machines, machines as complex as their macro counterparts, are ever to be made, several steps have to be completed. The fundamental one is discovering methods of fabricating parts on the appropriate scale. MEMS has hitherto been largely concerned with creating simple micro-systems comprised of bending beams or plates with associated strategies for detecting the motion of these elements. There have been attempts to create more complex devices, such as Sandia’s comb-drive motors made from a special process, but MEMS devices for the most part are still simple and limited in usefulness. A well-characterized process for creating arbitrarily complex shapes on the micro-scale will revolutionize MEMS, and open up many new areas and applications in the field of micro-systems.

The results: demonstrating that a complex scanning/multiple mask approach, which can create true three-dimensional forms in LiGA, is a significant step towards the fabrication of the miniature turbine using the same process.

D. FINANCIAL STATUS

The total funding for this task was $125,000 of which $75,706.58 has been expended.

E. PERSONNEL

This project is being worked on by Dean Wiberg, Beverley Eyre, Kirill Shcheglov, Dr. Philip Muntz (USC), and Eric Moore (Grad student, USC). Some tasks are being contracted (Swales Aerospace) or assisted by people at the Advanced Light Source at Berkeley Labs.

F. PUBLICATIONS

None.